RESEARCH DEPARTMENT

Pulse-code modulation for high-quality sound signal distribution: instantaneous compandors using diodes as non-linear elements

TECHNOLOGICAL REPORT No. EL-15

UDC 534.86
621.376.56

1968/7

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

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SUMMARY

In p.c.m. telephony systems, diode compandors are used to increase the signal-to-noise ratio. The report describes an attempt to apply the same principle to meet the more stringent requirements of a p.c.m. system for high-quality sound signals. The residual distortion produced by small errors in the transfer characteristics of compressor or expander was found to be unacceptable on some types of programme; it is not, however, considered practicable to reduce these errors to negligible proportions.

1. INTRODUCTION

The effective signal-to-noise ratio of sound transmission channels may be improved by the use of a compressor to reduce the dynamic range of the signal at the input of the channel and an expander to restore the dynamic range to its original value at the output. This process is called companding and the basic characteristics of it have been summarized in an earlier report in this series.[1]

In a coded transmission system, improved by a compandor, the distortion terms introduced by the compressor result merely in modification of the coded values transmitted, not in the production of out-of-band signals. The distortion terms are thus accurately reproduced by the decoder for cancellation by the expander. This characteristic permits the use of compressors and expanders operating instantaneously upon the signal waveform.

A method of instantaneous companding which has been applied to telephone circuits is the use of non-linear networks with diodes as the non-linear elements.[2] The present report describes an attempt to apply diode companding to a high-quality sound transmission channel. The attempt was made in order to assess the feasibility of making networks inverse to each other to sufficient accuracy to avoid audible distortion, and to explore the subjective effect of the programme-modulated noise which is an inevitable consequence of the companding action.[1]

2. THE ACHIEVEMENT OF INVERSE CHARACTERISTICS

For the purpose of the present experiment, it was necessary not only to match the transfer characteristics of the compressor and expander to a high degree of accuracy, but also to adopt a form of circuit that would allow the companding law to be readily altered. Both of these objects can more easily be achieved by circuits in which the desired characteristics are intrinsic, rather than those which depend on empirical adjustment.

Of the methods which intrinsically give the desired result, two which suggested themselves were (a) the use of identical non-linear networks in forward and feedback loops, and (b) the use of identical non-linear networks, the first operated in shunt between high source and load impedances and the second operated in series between low source and load impedances. For instrumental reasons, method (a) was found difficult to apply and method (b) (which was also the one used in the telephony application previously referred to[2]) was adopted.

The performance of compressor and expander networks using IN916 silicon diodes* was investigated; measurement was made at d.c., operating in one quadrant only of the input-output plane. Two compressor-expander pairs were used having initial slopes for the compressors of 4½ to 1 and 2½ to 1, corresponding to an improvement in signal-to-noise ratio of 13 and 8 dB respectively at low signal level.

The overall transfer characteristic of the 4½ to 1 compressor and expander was linear within ± 1½% of full-scale value and that of the 2½ to 1 compandor within ± 0·7%. This accuracy, obtained without either empirical adjustment or control of

* Since this work was completed, information published[3] by Bell Laboratories indicates that difficulties have been encountered in the use of ordinary silicon diodes for compandors in telephony and that special gold-doped diodes have been developed for this application.

the diode temperatures, was considered to be encouraging, and a symmetrical version of the system was constructed to enable experiments on programme to be carried out. Fig. 1 shows the transfer characteristics of the two compressors.

3. THE SIMULATION EXPERIMENT

For the experiments on programme the compressor and expander were introduced into an audio-frequency circuit. The presence of a p.c.m. system between the compressor and the expander was simulated by injecting Gaussian noise of equal power to the quantizing noise of the supposed p.c.m. system at that point. The experimental arrangement was as shown in Fig. 2 and the arrangement of the network as compressor or expander in Fig. 3. The compressor and expander diodes were enclosed in ovens which maintained the temperature constant within approximately ± 0·1°C. The input, intermediate and output amplifiers were flat in frequency response to approximately 5 MHz and were gain stabilized by approximately 20 dB of negative feedback.

The values of the resistors in the compressor units and the gain settings in the intermediate amplifier were adjusted on sine-wave signal for minimum total harmonic distortion at the output to produce the closest possible matching of the associated compressor-expander pairs. The lowest figures of total harmonic distortion obtained were 0·36% for the compandor of slope 4½, and 0·28% for the compandor of slope 2½, i.e. −48 dB and −51 dB respectively with respect to maximum signal.

Although at first sight the degree of residual distortion would appear to be sufficiently low, distortion was clearly audible on certain kinds of programme material such as piano music. An analysis of the harmonic distortion produced by the compandors is given in Table 1. The considerable content of high-order components may well account for the high audibility despite the low total harmonic figures.

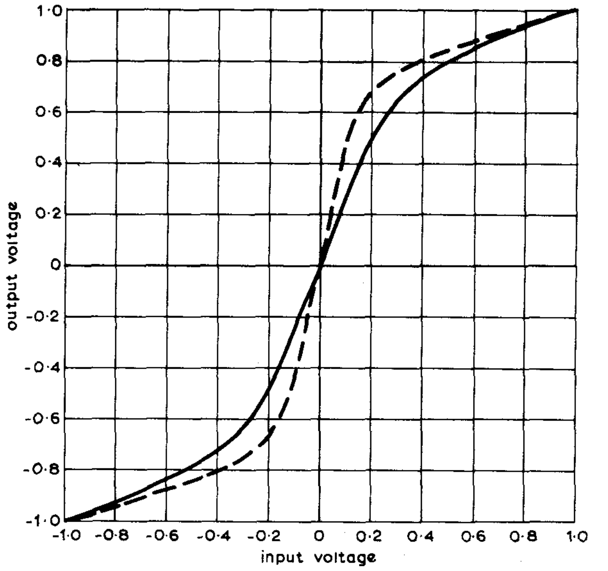

Fig. 1 - Compressor transfer characteristics

– – – – – Initial slope 4½ : 1
———— Initial slope 2½ : 1

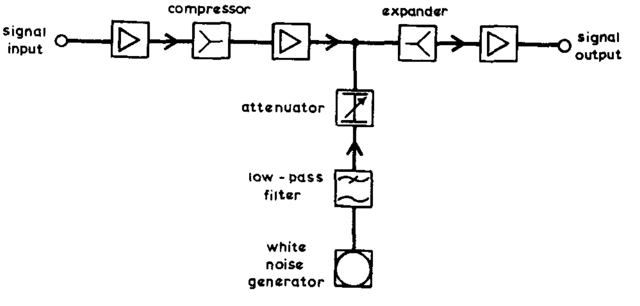

Fig. 2 - Block schematic of simulation experiment

Injection of simulated p.c.m. noise confirmed that the compandors were each giving the expected improvement in low-signal noise level. For injected noise equivalent to that from an 11-bit p.c.m. system, modulation of the noise by the expanders was not, however, clearly distinguishable from the distortion. Thus it was not possible to use the diode compandor to explore the subjective effect of programme-modulated noise.

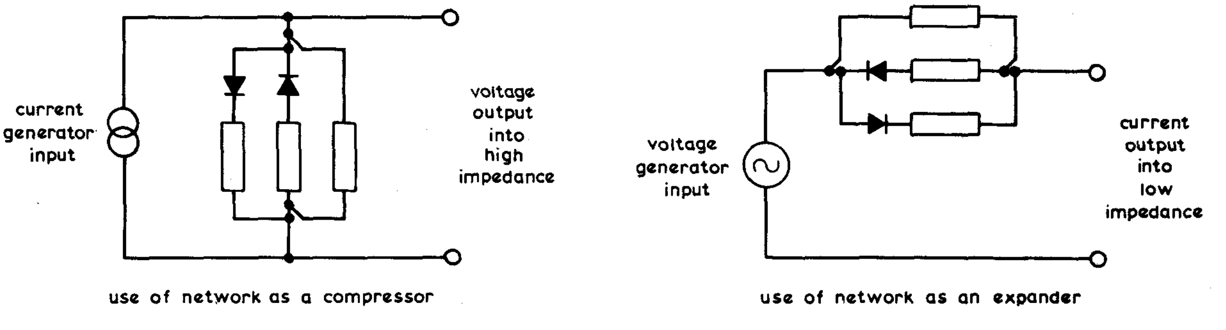

Fig. 3 - Use of network as compressor or expander

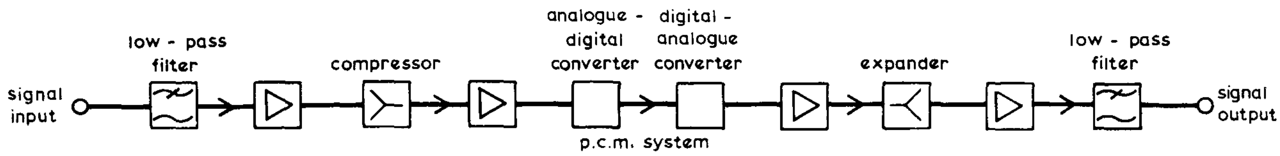

Fig. 4 - Block schematic of diode compandors in tandem with a p.c.m. system

4. THE DIODE COMPANDORS IN TANDEM WITH AN 11-DIGIT P.C.M. SYSTEM

In spite of the known shortcomings of the compandors it was thought advisable to operate them in conjunction with an available 11-digit binary p.c.m. system to check whether any unforeseen effects appeared. For this purpose, it was necessary to duplicate the amplifiers which had been interposed between the compressor and the expander and with suitable adjustments of signal levels to introduce the p.c.m. system at this point. A block schematic of the arrangement is shown in Fig. 4.

The harmonic distortion figures obtained with the compandor p.c.m. system operated in this way were some 5 dB worse than with the compandor alone. One of the causes of the deterioration was found to lie in the nature of the output signal from the digital-to-analogue converter (d.a.c.) of the p.c.m. system; this signal included between samples a brief excursion to the end of the output voltage range during each resetting period, which resulted in some unbalance of the current loading of the expander diodes. Although it would have been possible to modify the d.a.c. to provide a symmetrical output the generally unsatisfactory performance of the compandor apart from the p.c.m. system did not appear to justify the effort.

The audible performance of the system was consistent with the distortion measurements. No additional impairments which could be attributed to the interaction of the compandor and the p.c.m. system were heard.

5. CONCLUSION

It was felt that the difficulties in refining the instrumentation of diode companding to the point at which acceptable results could be obtained were greater than those which might be encountered in alternative companding methods, and that the effort would not be justified in terms of the low probability of success.

TABLE 1

Harmonic Analysis of Diode Compandors
Fundamental Frequency 1 kHz applied at Full Level

Harmonic No.	2·5 : 1 Compandor	4·5 : 1 Compandor
2	0·06%	0·08%
3	0·24%	0·30%
4	0·05%	0·02%
5	0·10%	0·15%
6	0·03%	0·02%
7	0·04%	0·08%
8	–	0·01%
9	–	0·04%
10	–	0·01%
11	–	0·02%
12	–	–
13	–	0·01%
Total r.m.s.	0·28%	0·36%

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Printed by BBC Research Department, Kingswood Warren, Tadworth, Surrey